The importance of preventive maintenance on steel reinforced concrete structures to impart sustainable development.

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Abstract

It is one of the functions of concrete cover to protect reinforcement to minimize corrosion from environmental effects. However, reinforced concrete structures in most cases suffer from corrosion of steel reinforcement and their service lives will be reduced. The steel in concrete is always prone to corrosion attack, and the reason being that concrete cover is porous in nature. Water from environment impregnates through pore space or through cracks and comes in contact with reinforcement. This paper highlights the importance of preventive maintenance on reinforced concrete structures in sustainable development. Preventive maintenance is the best corrosion control mitigation measure for reinforced concrete structures. Condition assessment of two reinforced concrete buildings has been made based on structural survey. Crack width varies up to 2mm in column and beams. It is suggested that new structures are to be constructed with corrosion monitoring systems.

Key words: reinforced concrete, preventive maintenance, service-life.

Introduction

Reinforced concrete is a powerful candidate material for construction in later of 20^{th} century. It enhances the development through construction of different infrastructures needed for several purposes. From production point of view, however, construction industry is an expensive sector in society more especially in developing countries. It consumes much energy in production and transportation of raw materials like cement and steel and in turn emits carbon-dioxide (CO_2) emissions in air. This emitted CO_2 has both environmental and social-economic impacts. Due to poor maintenance, there is an increasing deterioration of concrete structures in developing countries which affects the durability. To implement the concept of sustainable development, emission of CO_2 is to be reduced at various stages. It is not the technical sophistication of structural design that determines the durability of reinforced concrete member in a corrosive environment, but the detailing [1]. The provision of adequate drainage and a method of removing drainage water from the structure are particularly important. Corrosion protection of concrete cover is a function of both depth of concrete cover and w/c ratio [2]. The term maintenance becomes so important when it comes to limiting, controlling or servicing various defects that would lead to serious damage like corrosion of steel in reinforced concrete structures. There are three main types of maintenance as referred to reinforced concrete structure maintenance: 1. Preventive maintenance, 2. Repair/rehabilitation maintenance and 3. Collective maintenance.

"A stitch in time saves nine". This principle applies here whereby **preventive maintenance** simply means keeping an eye or monitoring the structure health and doing the necessary job on it to avoid defects or damage. **Repair and rehabilitation type of maintenance** means that if damage or symptoms of a defect found on reinforced concrete structure, the necessary procedure is done and it is fixed immediately. Any negligence at earlier stage of a defect leads to complications and deterioration. Unclean state of affair in one's house hold can lead to many diseases. **Collective maintenance** here means expensive repairs or rehabilitation of the defects on structure as well as non-recoverable damages that would cause risk to failure of a structure. In case of reinfocement corrosion it is possible to reduce the amount of repairs by avoiding the on set of corrosion. In other word, prevention is better than cure.

BRE Report 228293 (June 2006), Design service life is the assessment of a structure, both as complete building and individual components, which predicts its potential lifetime based on level of design, workmanship, maintenance and environment. Service life is the assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary [3].

In Figure .3, an example of a service life distribution is given.The parameters considered were mean value μ (magnitude parameter) and standard deviation (scatter parameter) (Siemes and Rostam, 1996) [4].

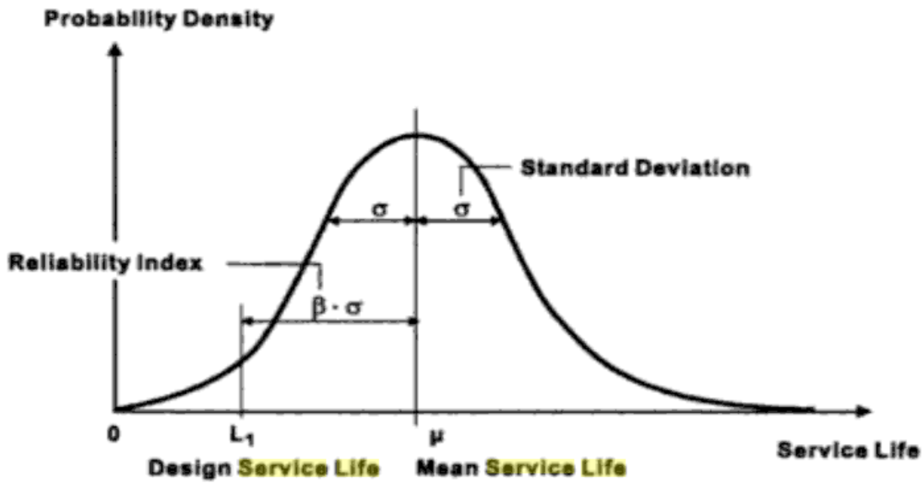


Fig.1: Example of probability density functions of a service life.

By means of the reliabily index, β,the probability that the service life is lower than the design service lif L_l is identified.Instead of the standard deviation, variation coefficient V may be used.

$$V = \sigma / \mu \qquad (1)$$

Table 1: Example of some reliability indexes in structural codes

Type of performance	**Reliability Index*In 50 years**		**Approximate Failure probability in 50 years**
	Euro Code (ECI,10/1994)	DUTCH Code (NEN 6700, 04/1991)	
Ultimate limit states (ULS)	3.8	3.6	10^{-4}
Serviceability limit states(SLS)	1.5	1.8	10^{-2}

Table.1. Shows the reliability index with the type of performance and their relative approximate failure probability for reinforced concrete structures according to Euro Code and Dutch Code .The Ultimate limit states (ULS) and reliability Indexes can be used in design service life to estimate failure probability for case onset of corrosion in reinforced concrete (Siemes and Rostam, 1996).

Back ground

Structure condition survey about corrosion of steel in reinforced concrete structures in the cities of Kigali- Rwanda and Bangalore- India was conducted as a part of big research program. It was focused at corrosion of steel in reinforced concrete structures in non-coastal areas. The survey targeted structure owners, construction and consultancy companies and government agencies as the source of the preliminary data about the perception about corrosion of steel in reinforced concrete structures. The details of the perception survey are not presented here but the summary results were as indicated in Table.2 below. This revealed the importance of preventive maintenance on reinforced concrete structures as correlated to sustainable development.

Table.2: Perception about corrosion of steel in concrete structures, a survey conducted in cities of Kigali-Rwanda and Bangalore-India.

City		Sex {M, F}		Level of education				Civil Eng/ related field		Copy of questionnaires			Response		
				Ns	P/S	H/S	UN	R	N	I	R	NT	Yes	No	-
Kigali	Structure owners	M		1	4	9	10	6	18	24	24	0	3	21	0
		F		1	2	7	5	0	15	15	15	0	4	11	0
	Consultancy company	M		0	0	0	8	8	0	8	8	0	2	6	0
		F		0	0	0	4	4	0	4	3	1	1	3	0
	Construction Companies	M		0	0	2	8	10	0	10	10	0	3	7	0
		F		0	0	0	5	5	0	5	5	0	0	5	0
	Government agencies	M		0	0	0	8	8	0	8	8	0	3	5	0
		F		0	0	0	4	4	0	4	4	0	1	3	0
Bangalore	Structure owners	M		0	3	12	5	2	18	20	18	2	6	11	3
		F		1	0	1	3	0	5	5	4	1	1	3	1
	Consultancy company	M		0	0	0	6	6	0	6	6	0	0	6	0
		F		0	0	0	4	4	0	4	4	0	0	4	0
	Construction Companies	M		0	0	0	6	6	0	6	5	1	3	2	1
		F		0	0	0	3	3	0	3	3	0	1	2	0
	Government agencies	M		0	0	0	4	4	0	4	4	0	1	3	0
		F		0	0	0	4	4	0	4	3	1	0	3	1
Total		**TOTAL**		**3**	**9**	**31**	**87**	**74**	**56**	**130**	**124**	**6**	**29**	**95**	**6**
		M	**86**	**1**	**7**	**23**	**55**	**50**	**30**	**86**	**83**	**3**	**21**	**61**	**4**
		% / 86		**1.2**	**8.1**	**26.7**	**63.9**	**58.1**	**34.9**	**100**	**96.5**	**3.4**	**24.4**	**70.9**	**4.7**
		F	**44**	**1**	**2**	**8**	**32**	**24**	**20**	**44**	**41**	**3**	**8**	**34**	**2**
		% / 44		**2.3**	**4.5**	**18.1**	**72.7**	**54.5**	**45.5**	**100**	**93.2**	**6.8**	**18.2**	**77.3**	**4.5**
Percent (%) out of 130		**M**	**66**	**0.8**	**16.2**	**6.2**	**66.9**	**56.9**	**23.1**	**66**	**63.8**	**2.3**	**16.2**	**46.9**	**3.1**
		F	**34**	**0.8**	**1.5**	**5.4**	**24.6**	**18.5**	**15.4**	**34**	**31.5**	**2.3**	**6.2**	**26.2**	**1.5**

{(**Sex: M**-male, **F**-female), (**Level of education: NS**-Illiterate, **P/S**-Primary school, **H/S**- high school, **UN**-University), (**Copy of Questionnaires**: **I**-Issued, **R**-returned, **NT**-not returned), (**Response**: Yes-accepted the possibility of corrosion in noncoastal area, **No**-denied the possibility area,(**-)**no reply)}

The survey about people's perception on corrosion of steel in reinforced concrete structures conducted in cities of Kigali-Rwanda and Bangalore-India, results indicated above (Table-2) caused the release of this paper as it showed that there is little awareness and reluctance to dealing with corrosion of steel in reinforced steel structures as an alarming issue. However literature and research has continuously shown a very big concern to this problem from different scenarios and with different case studies. They have as well suggested useful control and protective measures but not completely solved this problem. This is indicated by **73.1%** of 130 people asked denied the possibility of corrosion of steel in reinforced concrete structures, **91.5%** of 130 had university level and **75.1%** of 130 worked in a related field of civil engineering like construction and consultancies.

However in literature, it has been mentioned from long ago that the corrosion of steel reinforcements in concrete is one of the main reasons for the reduced service life of concrete structures [5].This means that if the life of reinforced concrete is shortened, the need of resources for repair and construction as well as demolition activities and residues (waste) will keep with an increasing pace. In the final report Brundtland commission (World Commission on Environment and Development, WCED) of 1987, the term sustainable development (SD) is defined as the development that meets the needs of the present without comprising the ability of the future generations to meet their own needs. This has a big concern to the construction industry right from design, construction and maintenance processes for reinforced concrete structures. Lofoten declaration of 1998 indicated that there was a challenge to construction industry, and still exists, of creating harmony and striking balance between construction industry activities with the natural environmental conservation [6]. Energy consumption in production or recycling processes as well as transportation will keep affecting local and global environment. Generally speaking, corrosion of steel in reinforced concrete structures is affected by internal and external factors. The factors that affect and influence reinforcement corrosion include but not limited to; poor construction practices and design quality, poor materials selection, lack of maintenance and exposure to a corrosive chemical environment [7].Corrosion process of Reinforcement in concrete starts with depassivation i.e. loss of oxide layer over the rebar and then propagate to reach a critical stage at which corrosion would produce spalling of concrete cover or cracking through the whole concrete as depicted in fig. 1 [8].

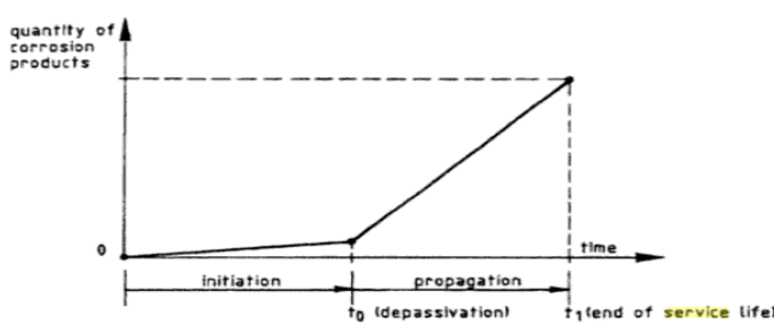


Fig. 2. Schematic representation of corrosion process

The corrosion rate of steel in concrete has been believed to be too slow to be of concern. Indeed as shown in Fig.1 above, under high alkalinity (pH > 13:5) of the pore solution, steel remains passivated with high degree of resistance against reinforcing steel corrosion initiation period (t_o). However, with passage of time some cover concrete would not be able to provide enough protection to steel reinforcement due to degradation of concrete and ingress of corrosive species from environment influencing corrosion propagation- The steady corrosion period (t_{corr}). The critical time (t_{cr}), as defined above can be expressed as:

$$\mathbf{t_{cr} = t_0 + t_1.} \qquad (2)$$

- $\mathbf{t_o}$> expected service life: this solution is quite safe, since depassivation of steel is avoided
- $\mathbf{t_1}$> expected service life: the safe level is not known precisely, as it is difficult to assess the propagation period due to the number of parameters involved.

Reinforced concrete structures perform well as long as the alkaline environment is intact as explained by Neville (Properties of Concrete, 1995) [9].Concrete acts as a special medium for corrosion reactions, and plays an important role in the corrosion process of steel in concrete. The pore solution contains various ions and it varies with cement used and the age of concrete. According to Barney back (1981), the pore solution composition is 0.6M KOH+ 0.2M NaOH +0.001M Ca $(OH)_2$ [10]. Micro cracking is the common defect. Cracks in concrete make the corrosion of reinforcement more rapidly than in non-cracked zones [11-14].The existence of cracks even with a small width (0.1 mm), Favra et al. 1997 [15] estimated 0.4mm, influences significantly the corrosion process. The diffusion of chloride ions and hence corrosion initiation period is ten times more rapid in a cracked than un-cracked concrete (Schiessl 19988) [16]. It paves the way for the ingress of detrimental species, so corrosion process will be further accelerated and self-catalytic process is triggered. The porous nature of conventional concrete, non-uniform distribution of pores, cover depth, quality concrete ingredients (water, cement, aggregates and admixtures), w/c, spalling and delamination can cause the differences in electrochemistry, and consequently generate micro galvanic corrosion cells on steel reinforcement. Autogenous shrinkage.ie shrinkage due to self-dissection is of magnitude of order 10^{-4} for ordinary concrete (w/c> 0.45). On field, concrete of low water- cement ratio is commonly used. In this case, non- negligible autogenous shrinkage that cause s stress and early cracking increases very rapidly, and it can reach 2 to 3×10^{-4} with water-cement ratio is < 0.4 (Tawaza and Miyazawa 1993) [17].However, the availability of water and oxygen at reinforcement level is a must to start corrosion process. The moisture content in concrete depends not only to the relative humidity of the atmosphere but also upon the temperature cycling during day and night [18]. Within 50–100% RH, the increase of environmental relative humidity decreases carbonation of concrete .Based on their calculation, Cahyadi and Uomoto have found that, within 50–30% RH, a decrease in environmental RH may not cause a decrease in carbonation of concrete especially in normal concentration of CO_2 even after a long period of exposure [19]. It has been observed that for a given w/c ratio, the coefficient of permeability of concrete increases considerably with increasing size of aggregates [20-21]. All the above mentioned concrete durability

issues in one way or the other, simultaneously or at random one influencing another, with time lead to initiation and propagation of corrosion of steel reinforcement. This shows that cover concrete is never free of defects, steel in concrete is always prone to corrosion attack, and hence the occurrence of corrosion of steel in concrete is a matter of time. Therefore, reinforced concrete structures call for maintenance especially preventive maintenance of it to sustain their designed service life.

Condition assessment of reinforced concrete structures

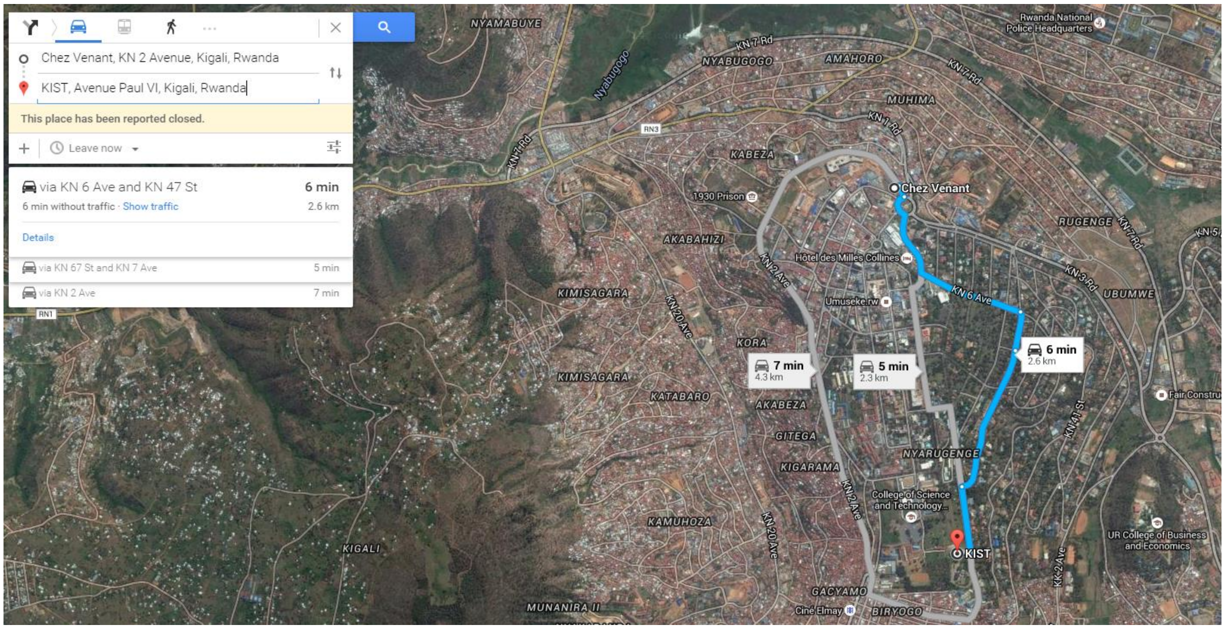


Fig.3 shows the location of Building (A &B), which are located 26km from each other (google map Rwanda, KIST to Chez venant) for the convenience of research ethics details not location details not provided.

Case study: Building-1 and Building-2.

Fig.4a **Fig.4b**

Fig.4a and 4b shows the pictures of one of identified buildings affected by corrosion of steel reinforcement.

Despite the claims of new discoveries of concrete materials and advancement in concrete technology, the fact remains that the present structural health (performance and durability) of concrete structures is a real set back. The structures shown in Fig.4a and Fig.4b were conditionally assessed and found with the state of reinforcement corrosion after 8 years and 25 years in service respectively. In large reinforced concrete structures, different members or parts of the same structure are exposed to different environments, so they may be attacked by corrosive agents differently hence the extent of corrosion damage would be different. The work objective was to investigate the causes of deterioration to the reinforced concrete structures of building-A and building-B and suggest the remedial solutions.

In most countries, especially developing countries like Rwanda, reinforced concrete structural health is at high risk of durability problems especially the corrosion of steel reinforcement. Topping other possible reasons to cause corrosion of steel in reinforced concrete is the deficiency in construction control practices [22]. Lack of reliable monitoring systems, less skilled man power and usage of adopted construction materials without any sufficient knowledge of their compatibility to the environment and future consequences has a significant effect to this problem. It has been said that Corrosion of steel in concrete problem has reached alarming proportions in the past three decades leading to every high repair costs, sometimes even above the initial construction cost, or the final collapse of the structure in extreme situation [23]. The Central Public Works Department, Government of India in its Technical Circular 1/99 reported that recent constructions in concrete were showing signs of distress in short time after completion as compared to 50 years old construction works [24].In his study, Viswanatha compared the performances of coastal concrete structures and those of structures away from the coasts and concluded that : “It generally takes about 4-5 years for the formation of hair cracks in locations away from the coastal belt. But another 5 years is sufficient enough to render the structure unserviceable. In coastal belts, the corresponding figures are 1-2 years and 4-5 years respectively.” [25].The problem of early decay and distress of concrete structures than designed service life mentioned in India is a common problem worldwide. Papadakis, et al said that “The last two decades have seen a disconcerting increase in examples of the unsatisfactory durability of concrete structures, specially reinforced concrete ones.” [26].

Methodology

Building-A and building-B are one of reinforced concrete structures identified for this particular research. Non-destructive testing techniques were done on them to validate the majority filling (Perception) about the corrosion problem as per survey findings of the previous work results in table.2. Photos were among the data acquired and recorded during visual inspection in this particular survey. Data from government and private institution reports sourced were also considered. The preliminary assessment was done and provided the initial analytical data for estimating the structural adequacy of an existing building and for establishing the need and priority for a more detailed analysis. The basic steps included: Available documents review, Site inspection and soil investigation, Preliminary analysis, Preliminary findings and recommendations. Detailed

assessment included: document review, building inspection, material analysis, structural analysis and detailed analysis. The detailed assessment though not necessarily presented here, was to determine if the building satisfied the required performance criteria or if it required rehabilitation. The procedure for condition assessment on both structures case studies (building-A and building-B) were generally the same except that tools and techniques employed were different depending on the particular requirement and condition of the structure on each particular case. For Building-A, the existing construction drawings did not contain information regarding the material properties used in the design. The concrete strength determined using the rebound hummer and the information related to the steel reinforcements was found by the use of the steel detector giving the reinforcement location, thickness of the concrete cover and the diameter. For building-B, Ultrasonic pulse velocity, half -cell potential and carbonation test tool and techniques were employed in acquiring data.

Results

Even though no statistics about the number of reinforced concrete structures affected by corrosion in whole city presently at this stage of research, this survey has come up with numerous examples of the reinforced concrete structures found with corrosion of steel reinforcement problem in both cities. Apart from detailed data tabulated in tables.1 and table.2 collected on the mentioned structures of building A and building B respectively. Figs.5a and Fig.5b below are some other photos of corroded members of reinforced concrete structures taken during visual inspection.

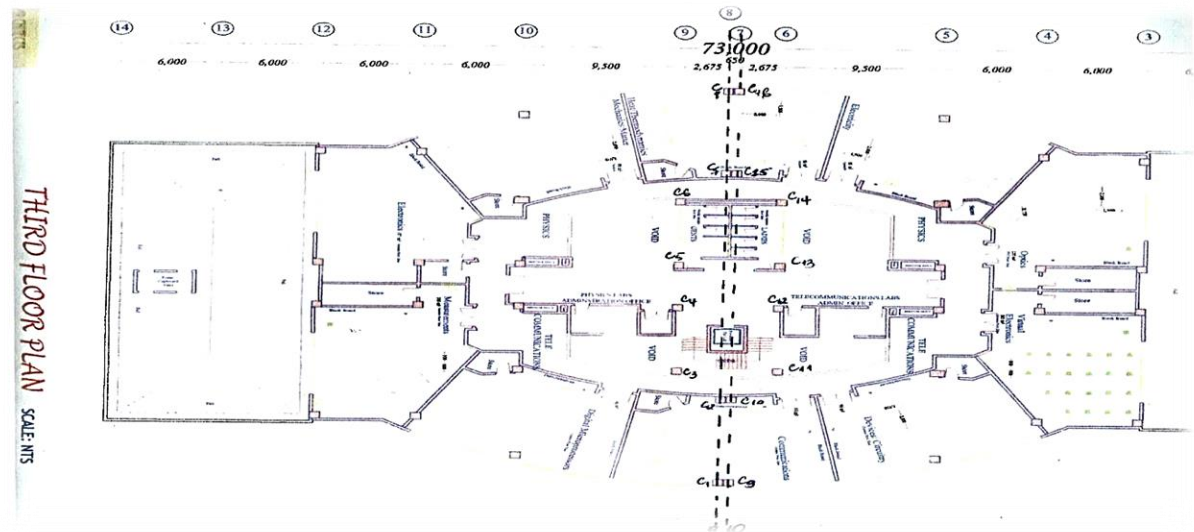
Fig. 5a

Fig. 5b

Fig.5a and Fig.5b are photos of corroded members on building-B (Photos taken during the survey in Kigali city)

It is needless to say that corrosion of reinforcement is active on concrete structural members of Fig.5a and Fig.5b. Neither has protective maintenance nor repair has been considered of importance than collective maintenance with such case of structural health conditions. It is reasonable to comment that sometimes protective maintenance on reinforced concrete structures is overlooked or neglected and it ends into irreversible state of reinforcement corrosion for reinforced concrete structures.

Fig .6 shows the third floor plan and the position of columns and beams for building-A [27].



From Fig.6, C_1 up to **C_{16}** above represents the columns of reinforced concrete structure-A as numbered from column1 up to column 16. The survey was conducted on 64 column members, 24 beam members and 20 masonry walls from ground floor to four floor and the results are tabulated in table-3.

The following Table-3 summarizes the data collected from a reinforced concrete structure found in Kigali city for the research purposes only.

Floor number 1	**Structural member** 2	**Cracks width (mm) Respective to columns (column2)** 3	**Concrete cover to the reinforcement (mm) Respective to columns (column2)** 4	**Crack length (m) Respective to columns (column2)** 5
I. Ground Floor	**Columns (C_n)** C_1, C_2, C_3, C_4, C_5 C_7, C_9, C_{10}, C_{12}, C_{13}, C_{14}, C_{15}& C_{16}	No cracks	31, 41, 38, 19, 31, 25, 37, 31, 24, 18, 34, 39 & 44	No cracks
	C_6, C_8, & C_{11}	1, 1.2 & 1	19, 32 &12	2.52,3.92 & 3.92
	Masonry wall (M_n) M_1	1	-	3.2
	Masonry wall (M_n) M_2, M_3, M_4, M_5	No cracks	-	No cracks
II. First Floor	**Columns (C_n)** C_1, C_2, C_3, C_4, C_5, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}& C_{16}	No cracks	32, 46, 41, 39, 47, 52, 41,50, 52, 37, 41, 54	No cracks
	C_6, C_7, C_8, C_{15}	1, 1, 1,1	19, 14, 14, 19	3,2.8, 3.38, 1

	Beam linking columns (C_n) C_1-C_2, C_9-C_{10}, C_3-C_4-C_5-C_6 C_{11}-C_{12}-C_{13}-C_{14} ,C_3-C_{11}, C_6-C_4	No cracks	43, 43, 34 41,41, 41	No cracks
	Beam linking columns (C_n) C_7-C_8, C_{15}-C_{16}	1, 1.1	28, 13	2, 2.30
	Masonry wall (Mn)-M1, M_4, M_5	1, 1, 2		2.1, 1.4 0.59
	Masonry wall (M_n)-M_2, M_3	No cracks		No cracks
III. Second Floor	**Columns (C_n)**-C_1, C_7, C_8 C_{10}, C_{13}, C_{15}, C_{16},	1, 1,1 2,1, 1, 1, 1	12, 13, 16 14, 14, ,12, 18	2.7, 1.8, 4.6, 3.8, 1.3, 1.2, 4.6
	Columns (C_n) C_2, C_3, C_4, C_5, C_6, C_9, C_{11}, C_{12}, C_{14},	No cracks	12, 30, 35, 40, 39, 16, 54, 57, 49	No cracks
	Beam linking columns (C_n) C_1-C_2 , C_9-C_{10}, C_3-C_4-C_5-C_6, C_7-C_8 C_{11}-C_{12}-C_{13}-C_{14} C_3-C_{11}, C_6-C_{14}	No cracks	41 41 51 51	No cracks
	Masonry wall (M_n) M_1, M_2 ,M_3, M_4	No cracks		No cracks
	Masonry wall (M_n) -M_5	2		1.4
IV. Third Floor	**Columns (C_n) -** C_1,	0.8	15	1.6
	Columns (C_n) C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{15}, C_{16}	No cracks	33, 39, 30, 30, 30, 30, 30, 30, 40, 43, 59	No cracks
	Beam linking columns (C_n) C_1-C_2, C_7-C_8, C_9-C_{10} , C_6-C_{14} , C_{15}-C_{16}, C_6-C_{14} C_3-C_{11}	No cracks	39	No cracks
	Beam linking columns (C_n) C_3-C_4-C_5-C_6	No cracks	35	No cracks
	Masonry wall (M_n) M_1, M_2, M_3,M_4	No cracks		No cracks
	Masonry wall (M_n) -M_1	4		2.80

The table-3 above shows crack width (mm), cover concrete depth (mm) and crack length(m) on concrete structural members columns, linking beams and masonry walls on three storey building .

The following Table-4 summarizes the data collected from reinforced concrete structure building-A and building-B found in Kigali city with nondestructive tools.

Building	1ST of const	Age (yrs)	1st evaluation & submission	1st evaluation study	UPVTQ N/mm^2/ rebound hammer	Half cell (H.P)	Cover-concrete depth (mm)	carbonation	Cl- (Kg /m3)	S0$_4$ (%)	PH	Grade of concrete (N/mm^2)
1	**2008**	**7**	**Feb /2015**	**25-27 Jan/2015**	Medium -Good concrete	-	**Column 12-52 Beam 25-45 Slabs 12-30**	Not to level of reinforcement	**0.16-0.24**	**2.889-3.38kg /m^3**	**10.5-11.66**	**In-situ strength 25**
2	**1990**	**21**	**24/11/2011**	**2/11/ 2011**		H.Probability of corr	**20-35**	to the level of reinforcement	**0.40 – 0.58**	**3.01-3.10**	**9.0 - 10.05**	**In-situ strength 3.2-3.4**

The data in table-4 is to indicate that with minimum maintenance reinforced concrete structures service life and performance can diminish with in short time than designed life.

Discussion of results

The synthesis of all the data collected in various tasks revealed that concrete deterioration has started one year after the construction works with formation of vertical cracks in columns and horizontal cracks in beams. The penetration of moisture and other corrosive agents through the cracks caused reinforcing steel corrosion leading to horizontal and vertical cracking and finally the delamination. The observed cracks in the bearing structure of the building-A, are as follows:

For the cracked bearing structure:

- The cracks are only in the columns and beams situated around the expansion joint,
- The cracks began to develop a year after construction of the building,
- Cracks roughly follow a straight line (the position of the main steel reinforcement longitudinal direction of the member),
- The concrete cover to the steel reinforcement of the cracked elements varies between 12mm and 52mm on the side of the expansion joint,
- The phenomenon of the concrete cover delamination was observed.

- For Building-B, it was due to aging of the concrete and less grade and insufficient cover concrete that resulted into carbonation. This cause spalling and delamination concrete deteriorated and finally corrosion of reinforcement reached irreversible stage.

Conclusions

- It was found that the cause of cracks that develop in the bearing structure of the building-A was the corrosion of the steel reinforcement due to the small thickness of the concrete cover on the steel reinforcements and the eventual roof leakage. The observed cracks in the masonry walls are due to the deformations of the bearing beams.
- Finally building-A was found reparable. However, spalling rate of concrete in building-B is very high since reinforcement are exposed as seen in Fig.5a and Fig.5b hence, it is necessitates reconstruction.
- For all beams cracked or connecting cracked columns could be strengthened or covered by carbon fibers: removal of unsound concrete, substrate preparation, application of Epoxy [sikadur-30], application of one layer of CFRP [sikaCarboDur Plates] and removal of air is necessary. All columns could be strengthened or covered by carbon fibers: removal of unsound concrete, substrate preparation, application of Epoxy [sikadur-230], application of one layer of FRP [sikaWrap-330C] and removal of air would fix the situation.
- The cracked structure members could be rehabilitated and reinforced using Fibre reinforced polymer technology.
- This research concludes that without maintenance corrosion in steel reinforced concrete structures is just a matter of time. The importance of preventive maintenance on reinforced concrete structures to sustainable development is significant.
- The new steel reinforced concrete structures should be incorporated corrosion monitoring systems to attain their designed service life with safe, less costly, timely maintenance

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